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(54) Method and system for reproducing audio frequencies.

(57) The present invention relates to a method and a system for reproducing audio frequencies in a sound reproduction system, comprising at least one loudspeaker (5) mounted in a loudspeaker cabinet and in which the frequency response (1) of the loudspeaker is equalized with a filter (4). Prior to feeding a signal into a wideband one-way loudspeaker (5) reproducing frequencies substantially over the entire audio range, the output of said loudspeaker being an audio signal, the frequency response (1) of the loudspeaker mounted to its cabinet is equalized with a filter (4), which is a wideband filter (4) also covering substantially the entire audio range. With the filter an approximate inverse response (2) is implemented in the desired passband of the loudspeaker system comprising said loudspeaker mounted to its cabinet, the inverse response being formed according to a frequency response of said loudspeaker system, which frequency response is a measured frequency response of said loudspeaker system. If desired, the measured frequency response can be averaged in the frequency domain and the inverse response is then formed from this averaged frequency response.

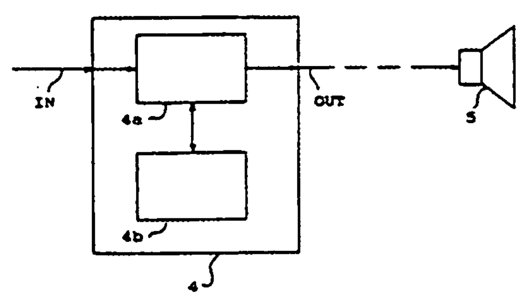

FIG. 2B

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The present invention relates to a method for reproducing audio frequencies in a sound reproduction system comprising at least one loudspeaker mounted in a loudspeaker cabinet and in which the frequency response of the loudspeaker is equalized with a filter. The invention also relates to a system for implementing the equalization method.

In prior art television receivers two-way or three-way loudspeakers are generally used. Television receivers with even four-way speakers have been designed. In such multi-way loudspeaker receivers an individual audio signal is divided to a number of loudspeaker elements. With the multi-way loudspeaker designs currently used, a better sound quality is sought.

In a multi-way loudspeaker system of prior art involves several problems. The multi-way loudspeaker system requires provision of separate loudspeaker elements for each frequency band. Also the crossover filtering of the frequency bands requires provision of extra components, and additional installations.

The use of several loudspeaker elements creates problems in the audio response. This problem is partly due to the fact that when low-degree division filters are employed, the power response is not optimal in the adjacency of the crossover frequency. The quality is also impaired because the mechanical structure of the loudspeakers has not been designed to be sufficiently optimal, this causing e.g. edge diffraction problems. Despite these problems multi-way loudspeaker systems are used because with one loudspeaker element a uniform frequency response cannot be achieved on the entire audio range.

The state of art is described below, reference being made to the accompanying Figure 1 which illustrates the amplitude response of one loudspeaker element of the state of art in an audio range.

Figure 1 presents the audio response 1 of a wideband one-way loudspeaker of the state of art. One may note in the figure that in the loudspeaker the variation range of the amplitude response may even reach 20 dB. Sounds with different frequencies appear at different volumes and the quality of the sound becomes poor. Such a loudspeaker is not appropriate to be installed in a television receiver.

Some other solutions for the equalization of loudspeaker frequency response are known in prior art. Two different solutions regarding the equalization are to be pointed out: In the publications US-4 109 107 and EP-145 997 a solution is explained, in which the equalization of the loudspeaker response, typically a woofer response, is done by identifying the values of parameters in a physical model of the said speaker, and the response is corrected by finding the inverse of the parameter values. In the publication GB-2 068 678 the loudspeaker response corrections are based on measurement and compensation of the amplitude characteristics by using tunable filter banks, where the correction is implemented typically by a fixed frequency width bank by adjusting the gain of each subband either manually or with some automatic means, often requiring iterative tuning procedures. The drawbacks of using bandpass filters with a fixed frequency bandwidth is that only the gain of the whole band can be adjusted, but it is not possible to consider small errors inside the band separately. Also the mentioned iterative tuning procedures are often very complicated.

The above mentioned US patent number 4 109 107 shows methods for the compensation of errors in the frequency response of a loudspeaker and these methods are based on a parametric model for the loudspeaker. The patent shows correction done in the area of the mechanical resonance of the speaker, compensation of the defects of the cone-air energy transfer characteristic and compensation of possible cone break-up characteristic. These corrections and compensations are dealing with the parameters of the loudspeaker and they do not provide correction of the whole frequency response when the loudspeaker is attached to a cabinet. The speaker-cabinet junction causes additional errors in the frequency response, but US patent 4 109 107 does not deal at all with correction of such errors.

The above mentioned European patent application number 145 997 deals with equalizing the loudspeaker response electronically. One way of performing this equalization is explained in the publication and it is based on the use of an analog state machine. Also there is mentioned that a digital counterpart can be formed whereby the calculations can be done digitally, but no details of the digital implementation are explained. As in US patent 4 109 107 also in EP 145 997 the idea is that an electrical model is determined according to the parameters of the loudspeaker and then the loudspeaker response is equalized by the use of an inverse model in a limited frequency band. As noted above, the drawback of using the values of a parameter model for the loudspeaker is that such a method does not consider errors in the loudspeaker frequency response caused by the speaker-cabinet junction, since the model considers the speaker only.

The object of the present invention is to implement a wideband one-way loudspeaker covering substantially the entire audio range, whereby the problems generated by multi-way loudspeakers can be avoided and the drawbacks of methods

based on a parameter model for the loudspeaker can be avoided. Also the complicated solution of using many bandpass filters to cover the whole frequency band of a wide-band one-way loudspeaker can be avoided. The aim of the present invention is therefore to overcome the above problems and deficiencies and to provide a method and a system for reproducing audio frequencies with which an acceptable sound quality can be achieved. For achieving said aim, the invention is characterized in that prior to feeding a signal into a wideband one-way loudspeaker reproducing frequencies substantially over the entire audio range, the output of said loudspeaker being an audio signal, the frequency response of the loudspeaker mounted to its cabinet is equalized with a filter, which is a wideband filter also covering substantially the entire audio range, and with the filter an approximate inverse response is implemented in the desired passband of the loudspeaker system comprising said loudspeaker mounted to its cabinet, the inverse response being formed according to a measured frequency response of said loudspeaker system.

The invention differs from prior art in that it is implemented by a digital filter, the inverse filter design can be done without iterative measurement procedures, and no characteristics of the corrective inverse filter are previously fixed (such as the frequency bandwidth), as in other methods, but can be determined during the design procedure, implying that the amplitude, phase of the combination of the amplitude and phase responses can be corrected, and also that the frequencies and the extent of the correction can be determined during the design procedure. Because the loudspeaker response is equalized according to a measured frequency response of the loudspeaker system comprising a one-way loudspeaker mounted to its cabinet, a much better result can be achieved, since the response is based on the actual loudspeaker system response and not on a model for only the speaker. A model is always incomplete, and it does not consider the effect of the speaker-cabinet junction and the acoustic interaction of the cabinet and the speaker, which are considered in the method and system of the present invention.

The system according to the invention comprises a digital filter with which a wideband, one-way audio system can be designed using one conventional loudspeaker element.

The invention is described below in detail, reference being made to the accompanying figures, in which:

Figure 1 presents the audio response of a wideband one-way loudspeaker known in the art,

Figure 2a presents the amplitude response of an equalization filter according to the invention,

Figure 2b presents a principle image of the implementation of the invention in a sound reproduction system, and

Figure 3 presents the audio response of the wideband one-way loudspeaker of the invention, equalized with an equalization filter.

Figure 1 is described above. The design according to the invention is described below referring to Figs 2-3 intended for the demonstration of the invention.

Figure 2a presents an example of the amplitude response of the equalization filter of the invention. The amplitude response is designated by numeral 2. The imperfections of the amplitude response of an individual loudspeaker element is compensated with the aid of a digital filter. A system and a program for designing equalization filters to implement the invention have been developed. In addition, a real-time equalization filter has been designed and implemented.

An equalization filter implementing an amplitude response according to Figure 2a is composed of a FIR filter and of one or more second degree IIR filters of biquand type, connected in cascade. The filter may, in fact, be implemented in a number of ways, and the essential feature is that the filter is a digital filter, preferably a filter including FIR and/or IIR filters.

For implementing the equalization filter of the loudspeaker, the frequency response of a one-way loudspeaker system comprising a one-way loudspeaker mounted in its cabinet is first measured. On the basis of the measurement result the properties for the equalization filter are established. On the basis of the measurements and requirements set for a loudspeaker, an inverse filter can be designed for equalizing the variations of the frequency response of a loudspeaker. One alternative is also that after having measured the frequency response of the loudspeaker system, the response is averaged by using an averaging method. In that case the averaging method averages the measured response in the frequency domain and the inverse response is then formed from this averaged response.

In designing an inverse filter implementing the amplitude response as shown in the example of Fig. 2a, a FIR filter was first designed in which the response is an inverse of the amplitude response of the loudspeaker system between selected frequencies, the intended passband of the system. Low sound frequencies, i.e. frequencies below 1.5 kHz, were equalized using second-order filter blocks. The bass response was expanded by one second-order filter block. In a filter implementing

the amplitude response as shown in Fig. 2a, the length of the FIR filter was 91, and three second-degree filter blocks were implemented with all-pass filters were used therein.

A digital filter can convenienty be implemented with a digital signal processor. For implementing the response of the exemplary case as shown in Fig. 2a, the sufficient calculation rate of a digital signal processor is about 10 MIPS. The processor must in such a case have at least 16 bit word lentgh. Such processors are readily available on the market. In the example, the dynamic range of the equalization filter was about 15 dB, see amplitude response in Fig. 2a.

Figure 2b illustrates an embodiment of the invention in a sound reproducing system, such as a TV set. The wideband filter 4 according to the invention, covering substantially the desired audio range and being a digital filter, can be implemented in a digital signal processor 4b programmed to implement a desired transfer function, i.e. frequency response 2 which is an inverse of the frequency response 1 of the loudspeaker system comprising a loudspeaker 5 mounted in its cabinet (not shown) and is connected to a digital sound processing circuit 4a of the sound reproduction system (here, a digital television sound processing circuit). In a television receiver according to the current state-of-the-art, the digital sound processing circuit 4a processes tone, volume, balance, and some other controls of the stereo sound and usually includes DA converters with which the sound signal is converted from the digital into the analog form for the loudspeaker 5. The sound processing circuit 4a and the digital signal processor 4b (implementing the actual filtering according to the invention) may constitute one part 4. Information (i.e. the sound in digital format) between the circuits 4a and 4b can travel e.g. in serial form. The filter 4 can be positioned in the sound reproduction system e.g. so that a signal IN entering the processing system is a signal from the intermediate stage of a tuner, such as the TV tuner, and an the processed and equalized analog sound signal OUT obtained from the filter 4 is, prior to being fed to the loudspeaker 5, be processed in a final amplifier stage.

Figure 3 presents the response of a one-way loudspeaker after equalization. The audio response is designated by a numeral 3. The amplitude response of the equalized loudspeaker is acceptable. The range of amplitude response variation of the original one-way loudspeaker was about 20 dB (see Fig. 1). The amplitude response variation of the equalized loudspeaker was about 6 dB for frequencies below 6 kHz, and in the entire passband, below 10 dB. The sound quality of the system equalized according to the invention was better than in a state-of-the-art multi-way loudspeaker systems. The audio power produced by the frequency equalized one-way loudspeaker was adequate. The sound appeared natural and did not contain any strong colourings.

The objective and subjective quality of sound of the system according to the invention was at least as good as in state-of-the-art receivers. Thanks to the invention, the power response of the loudspeaker, i.e. the power radiation pattern, can be optimized economically and much more carefully when only one element is used.

With the aid of the invention, the amplitude response problems caused by crossover filtering and concurrent radiation from several loudspeaker elements can be avoided. Also the efficiency of the sound reproduction is increased when components consuming power in the crossover filter can be eliminated.

This invention makes it possible to obtain a good sound quality by using only one loudspeaker element. One loudspeaker element is easier to install than several. No crossover filtering is needed. The mechanical structure of the receiver is simplified and assembly facilitated. This results in cost savings in series production.

The method suggested by the invention can be used not only for equalizing the amplitude response as in the above examples but also for equalizing also the phase response, or the combination of the amplitude and the phase responses. Generally speaking, for equalizing the frequency response of a one-way loudspeaker, whereby a uniform frequency response is achieved with a one-way loudspeaker substantially in the entire audio frequency range, preferably between frequencies 50 Hz to 20 kHz, depending on the sound reproduction system. The method and the system can be used in various sound reproduction systems, such as in television sets, particularly in digital TV sets, in sound reproduction amplifiers, telephone sound reproduction, etc. The reproduced frequency range in TV sets is usually from 100 Hz to 16 kHz, in telephones from 500 Hz to 4 kHz, and in HiFi systems from 50 Hz to 20 kHz.

Claims

1. A method for reproducing audio frequencies in a sound reproduction system, comprising at least one loudspeaker (5) mounted in a loudspeaker cabinet and in which the frequency response (1) of the loudspeaker is equalized with a filter (4), characterized in that
   - prior to feeding a signal into a wideband one-way loudspeaker (5) reproducing frequencies substantially over the entire audio range, the output of said loud-

speaker being an audio signal, the frequency response (1) of the loudspeaker mounted to its cabinet is equalized with a filter (4), which is a wideband filter (4) also covering substantially the entire audio range, and
- with the filter an approximate inverse response (2) is implemented in the desired passband of the loudspeaker system comprising said loudspeaker mounted to its cabinet, the inverse response being formed according to a measured frequency response of said loudspeaker system.

2. Method according to claim 1, characterized in that the measured frequency response is averaged in the frequency domain and the inverse response is formed from this averaged frequency response.

3. Method according to claim 1, characterized in that the response is an amplitude response.

4. Method according to claim 1, characterized in that the response is a phase response.

5. A system for reproducing audio frequencies, which provides at least one loudspeaker (5) mounted in a loudspeaker cabinet and a filter (4) to equalize the frequency response (1) of this loudspeaker, an electrical signal (IN) to be converted into an audio signal passes through the filter (4) into the sound reproduction system, the output thereof being an audio signal, characterized in that
   - the loudspeaker (5) is a wideband one-way loudspeaker reproducing frequencies substantially over the entire audio range, and
   - the filter (4) is a wideband filter covering substantially the entire audio range and implementing an approximately inverse response (2) in the desired passband of the loudspeaker system comprising said loudspeaker (5) mounted in its cabinet, the inverse response being formed according to a measured frequency response of said loudspeaker system.

6. System according to claim 5, characterized in that the measured frequency response is averaged in the frequency domain and the inverse response is formed from this averaged frequency response.

7. System according to claim 5, characterized in that the filter (4) is a digital filter.

8. Method according to claim 7, characterized in that the filter (4) comprises at least one FIR filter and at least one IIR filter.

9. System according to claim 7, characterized in that the filter (4) has been implemented with the aid of a digital signal processor (4b).

10. System according to claim 5, characterized in that the response is an amplitude response.

11. System according to claim 5, characterized in that the response is a phase response.

12. System according to claim 5, characterized in that the sound reproduction system is a television set.

13. System according to claim 5, characterized in that the sound reproduction system is a sound reproduction amplifier.

14. System according to claim 5, characterized in that the sound reproduction system is the sound reproduction system of a telephone.

15. System according to claim 5, characterized in that the frequency band of the filter and the loudspeaker is from 50 Hz to 24 kHz.

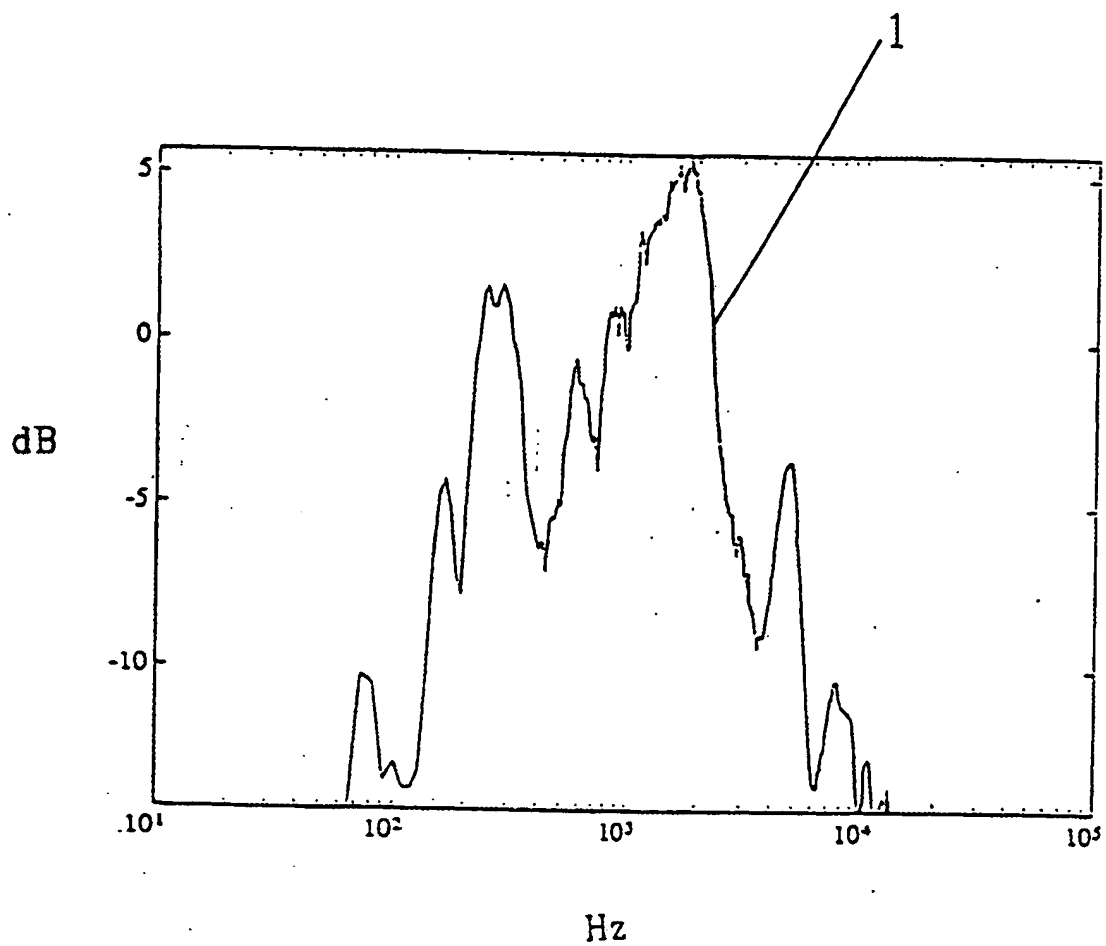

FIG. 1

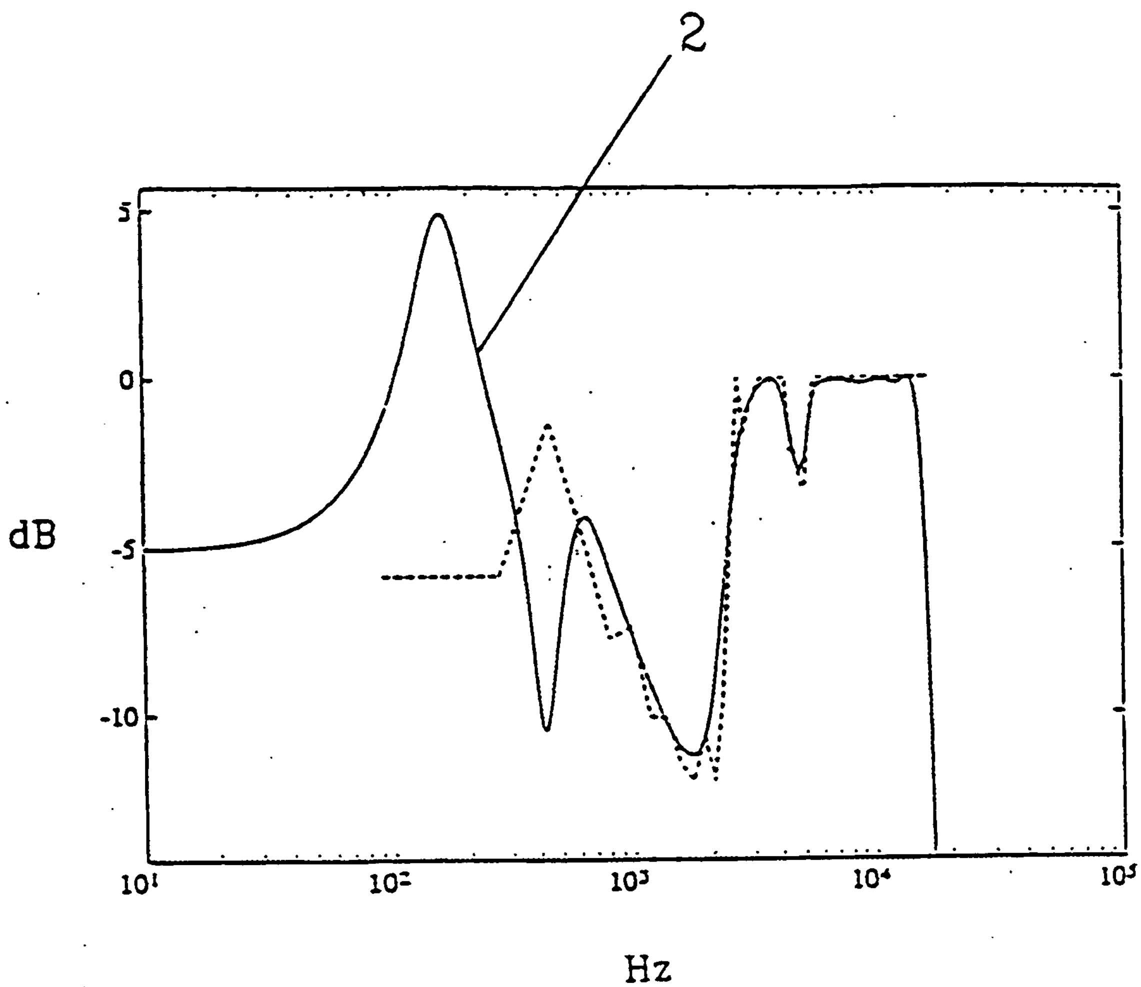

FIG. 2A

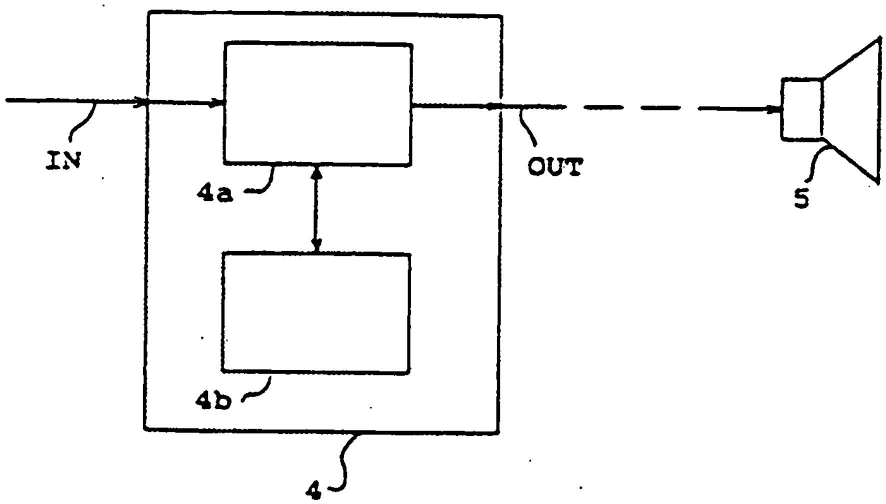

FIG. 2B

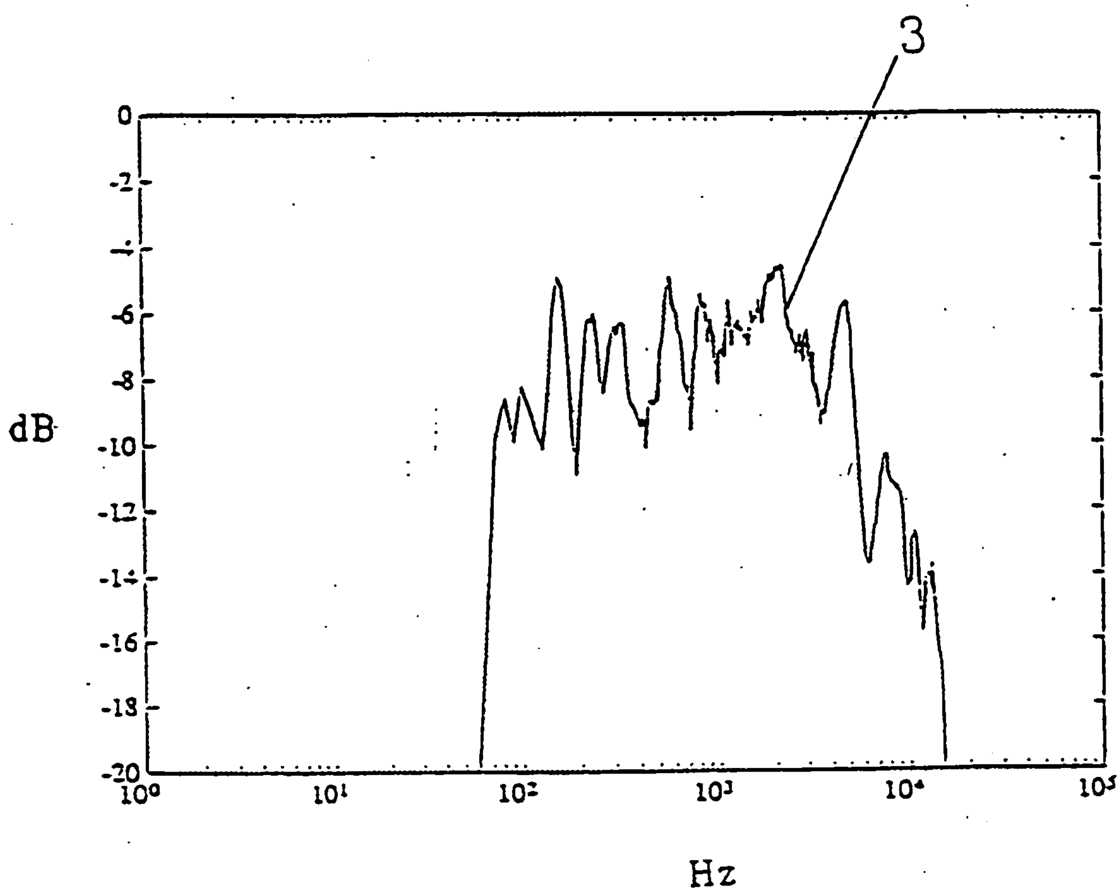

FIG. 3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 93 10 6371

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	EP-A-0 168 078 (PHILIPS)	1-8,10, 11,13	H04R3/04
A	* page 1, line 1-6 *	9,12,14, 15	
	* page 1, line 32 - page 6, line 5 * * page 13, line 5-14 * * page 13, line 25 - page 16, line 28 * ---		
Y	WO-A-9 102 407 (BELL COMM. RES.)	1-8,10, 11,13	
	* page 4, line 2 - page 5, line 4 * * page 10, line 9 - page 11, line 26 * * page 12, line 1-26 * ---		
Y	US-A-4 888 811 (TAKASHI)	1-7,10, 11,13	
A	* column 1, line 5-12 *	8,9,12, 14,15	
	* column 2, line 14 - line 28 * * column 3, line 36 - line 39 * * column 4, line 22 - column 7, line 44 * -----		TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			H04R H04L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	05 AUGUST 1993	ZANTI P.V.L.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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